MODELING STUDY OF PCBs IN THE HOUSATONIC RIVER PEER REVIEW

Modeling Framework Design
Final Written Comments

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RESPONSE TO CHARGE FOR THE HYDRODYNAMIC MODELING PEER REVIEW

I. General Overview of Response

It is the opinion of this reviewer that, as presently defined, this extremely ambitious project has a very small likelihood of success. There are a significant number of fundamental impediments (discussed in more detail below) to the successful implementation of the models that are proposed to be used, and these impediments must be overcome before any information useful to remediation decision-making can be developed. The modeling proposed goes far beyond current state-of-the-art and, furthermore, it is not at all clear that the scope of the problem to which the model is to be applied has been sufficiently analyzed at the outset. Each of these issues is discussed in more detail before proceeding to specific responses requested by EPA.

As this reviewer understands the problem, the modeling effort proposed is to test the impact of specific proposed remediation decisions against a baseline "no action" condition. The "no action" baseline condition itself encompasses several possible hypotheses regarding the outcome of the remedial activity that is currently underway in the upper reaches of the east branch of the Housatonic River. In this "no action" baseline analysis it is proposed that a 50-70 year simulation be performed to describe the sediment and PCB transport within the broad river valley (encompassing both the meandering river channel and the proximal and distal flood plains). These simulations are expected to include the range of hydrologic conditions that could be expected to occur over this time span. The outcome of this hydrologic-hydrodynamic modeling is to be employed in an additional model to determine the biological impact of the remediation scenarios.

The key factor in the analysis of the system is its innate complexity, which includes the meandering river channel, the interactions between the river and associated wetlands, banks and floodplains, and the extreme variability in the rates of erosion that have been associated with the river bed and channel sediment heterogeneity. Overlaying this great complexity is the apparent fact that almost half of the PCB currently in place in the river valley sediments appears to be resident in sediments (and at some points deep into the sediment) that are located out of the currently existing river channel. This fact alone is prima facie evidence that out-of-bank flows will be a key factor in the future fate of the extant PCB in the sediments. It also serves to underline the emphasis that needs be placed on the possible future migration of these out-of-channel sediments.

The recent historical record (1944 on) indicates that channel reformation, either through ongoing bank erosion, or through extreme flood events, has lead to 6-10 significant modifications in the river channel geometry. This is evident in the plan form maps of the river valley, which appear to indicate substantial wetlands adjacent to and associated with the river. It is not clear if the formation of these wetlands is a result of ongoing river rechannelization by bank erosion or prior major flood events, or both.

Thus it is clear that out-of-bank flows and the associated sediment transport are going to be a significant factor in predicting the fate of a substantial fraction of the existing PCBs, especially given the fact that field data show that even frequent annual high flow conditions can lead to sediment transport rates that increase by as much as two orders of magnitude over normal river flows.

The basic problem is that there is no known numerical model that is capable of predicting flood plain and bank erosion in a quantitative and verified way. Another major problem is associated with the high degree of meandering that occurs in the Housatonic River. Out-of-channel flood events in highly sinuous rivers usually lead to a complete realignment of the flow vectors once the river is significantly out of its banks. This means that the hydrodynamic model has to be capable of both tracking the flow within the meandering river when in-bank flow occurs, while at the same time retaining the ability to realign flow directions when the river occupies a significant fraction of the flood plain. In so far as is known, no single two-dimensional model has ever accomplished this successfully for the flow field, let alone also include the associated sediment transport. It is possible that a three-dimensional model could be successfully used over a limited section of the river, but application of such a 3-D model to the entire river reach is probably not computationally feasible, and in any case would still be subject to the sediment data limitations discussed below.

It is likely that a useful model could be developed that was restricted to in-bank flow. It is also highly likely that modeling of the significant over bank flows could also be successfully completed. However, it would require a different model in each case. In fact, one-dimensional models are widely used for these purposes. Specific examples include HEC-2 (Corps of Engineers), NWS Flood Wave, Fischer Delta Model (Hugo B. Fischer, Inc.), DWRDSM2 (Calif. Dept. of Water Resources), and there are probably many others. These one-dimensional models are widely used and have been calibrated and verified to exacting standards for both flow rates and water surface elevations, which is a necessary first step in sediment transport analysis. (For a discussion of some available models see the publication "River Hydraulics", American Society of Civil Engineers, 1996). What is missing from the MFD is any meaningful discussion as to why these models were not considered, or even used, before the project decision was made to proceed with a fully two-dimensional model in an extremely complex and hitherto unproven application.

It appears that in-bank flow occurs probably most of the time and is probably responsible for perhaps half of the total annual transport of material within the river. However, as the data analysis presented by GE indicated, the eight major flow events analyzed for 1999 each can carry as much as two orders of magnitude more sediment over a one day period as would normally occur. Furthermore, at this point no one even seems to know what sediment load a 10-year or 20-year flood event would carry, or the lateral extent of the river migration during such an event. The likelihood of such an event occurring within the 50-70 year simulation period must be seriously entertained.

Perhaps most perplexing of all about this project is the fact that the data that have been collected regarding river flow rates and associated sediment and PCB fluxes, do not yet seem to have been analyzed in any comprehensive detail. A careful analysis of these data would indicate the relative sinks and sources of sediment and PCB within the river, and also provide an indication of the relative importance of in-bank versus out-of-bank flows. A detailed analysis of these data would also provide the rates of erosion and the rates of deposition along the river, and how these rates were related to the rising and falling hydrographs. It would also provide estimates of the current fluxes of PCB under a variety of flow conditions. This information would be of consummate value in providing the type of cross-sectionally averaged data that could be used to calibrate a one-dimensional model of the system. It would seem highly appropriate to complete this analysis even before launching into a modeling exercise. This reviewer has some difficulty in understanding why this has not been done, or if it has been, why it is not discussed.

The model that is proposed will attempt to describe the rates of erosion and deposition on a 20-meter grid plan. As the field and laboratory data collected by the Corps of Engineers would strongly suggest, predicting the rates of erosion on a grid this small cannot avoid the substantial error that is associated with the heterogeneity of the sediments. It is implausible to think that the riverbed sediments can be characterized on a grid scale this small, so that attempting to model the fate of the sediment on such a scale appears quite inappropriate. In any case, the model output is to be aggregated to such an extent that the output will be used in AQUATOX on a grid scale that is about 250 times as large. The mismatch between the two spatial scales of the sediment transport model and the ecological model makes little sense, especially since the critical data necessary to predict erosion rates cannot be practicably known on the small scale proposed for the EFDC modeling.

However, it does appear that reasonable data are available to analyze the laterally averaged rates and extent of erosion and PCB transport that occurs for distinct and identifiable reaches of the river. It therefore would appear to make much more sense to use these data to calibrate a transport model that is based upon a one-dimensional representation of the river system. Furthermore, the one-dimensional model need not be uniformly valid over all ranges of flow. The use of two or more models separately calibrated to in-bank and out-of-bank flows would be quite appropriate.

In summary, the approach that EPA is proposing is, in the opinion of this reviewer, inappropriate with little chance of success. Alternative approaches that can usefully employ the (seemingly as yet unanalyzed) data collected to date would appear to be far more fruitful and should have been attempted prior to launching into a modeling exercise that has so many unresolved issues. If indeed the one-dimensional approach discussed above proved fruitless (which seems very unlikely) at least there would be a strong indication of the key factors to address in a more comprehensive modeling exercise. EPA has made a fine job of categorizing every and all possible phenomena that could enter into the problem. However, there is no evident effort to order, or scale on a basic level, the relative importance of the processes that enter into the transport and fate of the PCB in the river valley. This is a crucial first step that could be easily accomplished with the data that are available.

II. Response to Peer Review Questions

In considering the foregoing general issues and evaluating the EPA documents, the Peer Review Panel shall give specific consideration to the following questions. As modeling activities proceed, additional specific questions may be identified the panel to address.

A. ***Modeling Framework and Data Needs***

1. ***Do the modeling frameworks used by EPA include the significant processes affecting PCB fate, transport, and bioaccumulation in the Housatonic River; and are the descriptions of these processes in the modeling framework(s) sufficiently accurate to represent the hydrodynamics, sediment transport, PCB fate and transport, and PCB bioaccumulation in the Housatonic River?***

The modeling framework used by EPA is believed to be inappropriate. Unquestionably all of the processes that could affect the fate and transport of PCB in the Housatonic River appear to be well catalogued. However, what is missing is any experience or data analysis to suggest that the processes are captured correctly, or to the proper scale. As noted above, a careful interpretation of the existing data would help resolve this primary deficiency. In some cases there is an attempt to be too all encompassing, which is exemplified by the use of the two-dimensional EFDC model when the likelihood of obtaining sufficient sediment data at the grid scale to characterize either the soil heterogeneity, or the erosion/deposition data needed for calibration, is extremely remote.

2. Based upon the technical judgment of the Peer Review Panel:

a. ***Are the modeling approaches suitable for representing the relevant external force functions (e.g.. hydraulic flows, solids and PCB loads, initial sediment conditions, etc.), describing quantitative relationships among those functions, and developing quantitative relationships between those functions and PCB concentrations in environmental media (e.g., water column, sediments, fish and other biota, etc.)?***

Representation of the hydraulic forcing functions via the HPSF modeling is appropriate, whether the sediment and PCB loads will be adequately represented is another question altogether and this may take some careful analysis. What would be desirable is to establish a sediment rating curve for the section of river above the modeling reach. There are some data available to do this but it is not clear that there are sufficient data for the high level out-of-bank flows that are going to impact the PCB transport in a significant way. Extrapolation of the rating curve to these high flow conditions could be done by reference to data records for streams of a similar nature. Similarly, there is a vast literature on the partitioning of PCBs between sediments, water and fish and it seems unlikely that this river has sufficiently unique features that these data bases from elsewhere cannot be used to supplement the data available from the prior field work on this river. However, it seems that the use of an overall partition coefficient that does not recognize the fractional mass of chlorine atoms present may present some problem.

b. ***Are the models adequate for describing the interactions between the floodplains and the river?***

As made clear in the discussion above, this reviewer believes that the model chosen to describe the water flow and sediment transport in the river is not appropriate. There is no prior experience with the application of a single model to such a sinuous and meandering river over a complete range of flow records that include out-of-bank flows. At transition from in-bank to out-of-bank flow the flow vector distribution becomes very three-dimensional and it is very unlikely that a two-dimensional depth-averaged model can properly capture this transition. There is no reason that bounding estimates of the normal in-bank flow and out-of-bank high flows cannot be well described by the application of two different one-dimensional models.

c. ***Are the models adequate for describing the impacts of rare flood events?***

Given the sinuous nature of the river and the large number of meanders it is likely that the river will have a complete change in flow pattern when it flows out-of-bank. It is not clear how often such flow transitions will occur and whether they really are so rare. Given the presence of the PCB on the flood plains it would appear that they are not so rare. The transition from in-bank to out-of-bank flow is therefore very dramatic in terms of the directional distribution of the flow vectors. Successfully describing such a process with a two-dimensional model is believed to be implausible and there are no known verified applications of a two-dimensional model in this context. It would seem more appropriate to use two separate and distinct one-dimensional models for each of these two distinct flow situations. As described in the general comments above, it is known that such models do work in these contexts and there are a large number of verified flow applications.

d. ***Are the models adequate for discriminating between water-related and sediment-related sources of PCBs to fish and other biota?***

This reviewer is not totally competent to offer a substantive opinion with respect to this issue. However, it does appear that the primary issue may be the partition coefficient for the PCBs and the reviewer is not at all sure that the partition coefficients have been adequately described. It is known that there are very large differences in this coefficient between low chlorine and high chlorine PCBs. This issue does not seem to have been addressed in any detail. The measurements of the partition coefficient that have been made relate the coefficient to distance from the GE site, which may be a reflection of the partitioning with respect to chlorine weight. Furthermore, the measurements of partition coefficient in the sediments were made on centrifuged sediment samples rather than core squeezed samples. Some investigators are of the opinion that centrifuging to obtain pore water samples does not give a true representation of the concentration of tracers within the movable pore water. Comparisons between squeezed and centrifuged samples for other halogenated hydrocarbons (e.g., DDE) have shown very significant differences in partition coefficient.

3. Again, based upon the technical judgment of the Panel, are the spatial and temporal scales of the modeling approaches adequate to address the principal need for the model - producing sufficiently accurate predictions of the time to attain particular PCB concentrations in environmental media under various scenarios (including natural recovery and different potential active remedial options) to support remedial decision-making in the context described above in the Background section? If not, what levels of spatial and temporal resolutions are required to meet this need?

This issue has been addressed above at some length. To reiterate, it is believed that the spatial scaling intended for the EFDC modeling is congruent neither with the sediment data that are necessary to specify erosion, nor the flux data that will be used to calibrate and verify the model. In any case there is a substantial mismatch between the scales of application of the AQUATOX and EFDC models. As explained above, cross-sectionally averaged data, as would be used in a one-dimensional model may be quite adequate for a description of the efficacy of remediation processes. If it is not, then we need to understand why it is not before proceeding with a fine-scaled model that may only be accurate when the flow is in the basic river channel.

4. Is the level of theoretical rigor of the equations used to describe the various processes affecting PCB fate and transport, such as settling, resuspension, volatilization, biological activity, partitioning, etc., adequate, in your professional judgment, to address the principal need for the model (as defined above)? If not, what processes and what resolution are required?

The basic problem is not with the theoretical rigor of the equations, but with the context within which they are placed. For example, the description of resuspension and erosion of particles can be described quite adequately by using the empirical data developed by the SEDFLUME apparatus. The issue becomes how to use these data in the modeling when it is known from the sediment sampling in the river channel and flood plains that the sediments are extremely variable with respect to the rate of erosion. It is not possible to describe completely the surface and depth distribution of the sediment properties that control erosion at the fine scale necessary to apply a two-dimensional model with a 20-meter (or less) grid scale. However, from the sediment flux data that have been developed in the field it should be possible to give average sediment properties that can be used to describe in a general way the resuspension of river bed sediments and flood plain sediments. This is not unusual in fluid mechanics; sometimes less is more. There are many examples of flow calculations that work extremely well in one-dimension and yet cannot be modeled with any accuracy in two or three dimensions (pipe flow is an obvious example).

5. What supporting data are required for the calibration/validation of the model on the spatial and temporal scales necessary to address the principal need for the model (as defined above)? What supporting data are required to achieve the necessary level of process resolution in the model?

This reviewer is of the opinion that there are probably adequate data collected already for the calibration and verification of a one-dimensional fate and transport model. The data inventories suggest that at least there is the quantity of data necessary. However, it is not at all clear that the quality of the data is adequate. For example, the description of the May 19-21 storm event by GE and EPA showed some fairly substantial discrepancies in magnitude of sediment concentrations, and timing of flows. In addition, a quick review of the data provided by EPA in response to Question 85 shows some unusual and inconsistent behavior for the sediment concentrations in relationship to the flood hydrographs plotted at several locations. These data need a very careful analysis, interpretation, and appraisal, before they are used to calibrate and verify any modeling. It is not clear that this appraisal has yet been performed.

6. Based upon your technical judgment, are the available data, together with the data proposed to be obtained by EPA, adequate for the development of a model that would meet the above referenced purposes? If not, what additional data should be obtained for these purposes?

See answer to the previous question. This question cannot be answered without some interpretation of the existing data. The inconsistencies that became apparent at the Peer Review meeting would seem to indicate that there could be some problems that need addressing.

III. Specific Comments on the Modeling Framework Design Report and/or the Quality Assurance Project Plan.

The EPA response to the questions posed by the Peer Review Committee was not always forthright. For example, on page 2, EPA states:

" Although the application of these three models in such a coupled framework has not been previously developed, particularly for a complex meandering river such as the Housatonic River with the associated flood plain, each of the individual models has a lengthy (~10-20 year) history of successful applications to a wide range of waterbody types and problem settings, including linkage with other models."

The fact is that the EFDC model has not ever been successfully applied to the major problem being faced here, where about 50 percent of the transport occurs while the river is within its channel boundaries (where the EFDC model has been previously used), and about 50 percent appears to occur in the infrequent periods when the river moves out of its sinuous boundary and onto a flood plain. There is no history of successful application of any one model in this circumstance and there is no good reason to believe that the two-dimensional EFDC model can be successfully applied in this context.

EPA states (response, page 14): "Since this class of hydrodynamic models are based on first-principle physics, the hydrodynamic regime of both small and large water bodies can be simulated accurately as long as proper boundary conditions are imposed ...."

This is not correct. EFDC is not a first principle model. It is a model that uses the time-averaged Navier-Stokes equations with a turbulence closure model that requires empirically defined coefficients. If it were a first principle model it would solve the Navier-Stokes equations in a direct numerical simulation. This is a common misrepresentation by turbulent flow modelers, that they are using first principles, when in fact they are not. The fact is that these turbulence models have not yet been able to describe properly even the simplest hydrodynamic flow over an extended range of Reynolds number, e.g., determination of the drag coefficient for turbulent flow past a sphere. Nevertheless, the models have gained some measure of acceptance because they appear to be capable of reproducing the gross features of some large-scale flows. In other cases they have failed completely (e.g., Santa Barbara Channel). The failures seldom ever get published.

IV. Concluding Comments

Overall, the basic criticism of the modeling plan remains the fact that there are so many complex difficult modeling issues that remain unresolved and are yet to be addressed. As a consequence there is no clear indication that the project as currently planned will be at all successful. An initial application of a more conventional "bounding " analysis on the data already collected would more than likely be far more profitable, especially if this were coupled with the application of simpler proven models. If and when these simpler models do not work is the appropriate time to consider others with a higher degree of complexity. (See "The Neglected Art of Bounding Analysis", Environmental Science and Technology, page 162A, April 1, 2001).